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FIG. 1B

(57) Abstract: Optical components that maintain transparency (remain clear) in high energy environments, including in applications of high-intensity gamma-ray radiation dosage of 1.29×10^9 rads and greater, and neutron energy at neutron fluxes ranging from 3×10^9 to 1×10^{14} n/cm² sec and greater, and fluencies ranging from 2×10^{16} to 8.3×10^{20} n/cm² and greater. Further, the optical components have a bulk laser damage threshold of 105 ± 20 J/cm², a surface laser damage threshold of 72 ± 15 J/cm², a Stokes shift of about 9%, and a fractional thermal loading of about 11%.



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[001] OPTICAL COMPONENTS FOR USE IN HIGH ENERGY ENVIRONMENT
WITH IMPROVED OPTICAL CHARACTERISTICS

[002] CROSS-REFERENCE TO RELATED APPLICATIONS

5 [003] This Application claims the benefit of priority of the co-pending U.S. Utility
Provisional Patent Application No. 61/198,012, filed 31 Oct 2008, the co-pending
U.S. Utility Provisional Patent Application No. 61/180,880, filed 24 May 2009, the
co-pending U.S. Utility Provisional Patent Application No. 61/185,190, filed 08 June
2009, and the co-pending U.S. Utility Provisional Patent Application No. 61/218,971,
10 filed 21 June 2009, the entire disclosures of all Applications are expressly
incorporated by reference in their entirety herein.

[004] BACKGROUND OF THE INVENTION

15 [005] Field of the Invention

[006] This invention relates to fluorophosphate based optical components with
improved optical characteristics for use in high energy environments.

[007] Description of Related Art

20 [008] Some of the known conventional optical components have some levels of
radiation resistance, but that level of resistance is not sufficient for their use in high
energy environments.

[009] Examples of optical components with different levels of radiation resistant
25 characteristics can be seen in bismuth metaphosphate based glass systems that
solarize after being exposed to a few hundred kilo rads of gamma radiation. Other
examples include the SiO₂ base optical components, which are well-known as poor
performers under high energy environments in that they darken under very low levels
of gamma radiation, making them very impractical for uses in high energy
30 environments. Other optical components comprised of phosphate based glasses of
varying compositions contain alkaline elements, which are also known to actually

reduce and lower the overall radiation resistance of the final product, thus rendering them very impractical for use in any high energy environments. Other optical components used include the germanium dioxide based network structures, which are not suitable for radiation resistance due to the presence of GeO_2 .

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[0010] With respect to the optical characteristics of the above optical components and, in particular in relation to their surface laser damage threshold, most have a very low surface laser damage threshold as indicated in the following table:

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[0011] Surface Laser Damage Threshold

Optical Component	Surface Laser damage threshold
Schott glass Products phosphate glasses LG750	$\sim 30 \text{ J/cm}^2$
Corning glass products silica glasses 7940	$\sim 38 \pm 2 \text{ J/cm}^2$
Corning glass products borosilicate glass 0211	$\sim 32 \text{ J/cm}^2$
Bismuth containing fluorophosphate glass	$\sim 29 \text{ J/cm}^2$

[0012] Therefore, the above optical components cannot be used in high laser energy environments, which requires thresholds that are 60 J/cm^2 or higher.

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[0013] Accordingly, in light of the current state of the art and the drawbacks to current optical components, a need exists for an optical component that would have a high-energy resistance and superior active and passive optical characteristics.

[0014] BRIEF SUMMARY OF THE INVENTION

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[0015] The present invention provides optical components that maintain transparency (remain clear) in high energy environments, including in high-intensity gamma-ray radiation dosage of 1.29×10^9 rads and greater, and high neutron energy at neutron fluxes ranging from 3×10^9 to $1 \times 10^{14} \text{ n/cm}^2 \text{ sec}$ and greater, and fluencies ranging from 2×10^{16} to $8.3 \times 10^{20} \text{ n/cm}^2$ and greater. Further, the optical components have a bulk

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laser damage threshold of $105 \pm 20 \text{ J/cm}^2$, a surface laser damage threshold of $72 \pm$

15 J/cm², a Stokes shift of about 9%, and a fractional thermal loading of approximately 11%.

[0016] One exemplary aspect of the present invention provides an optical component,
5 comprising:

a metaphosphate Ba(PO₃)₂, 10 to 60 mol %;

a metaphosphate Al(PO₃)₃, 10 to 60 mol %;

fluorides BaF₂+RF₃, 20 to 90 mol %;

where R is selected from one of Y and La;

10 with dopant selected from one of Yb₂O₃ and YbF₃ 0.5 to 10 wt% over 100.

[0017] Another exemplary aspect of the present invention provides an optical component, comprising:

An optical component, comprising:

15 a metaphosphate Ba(PO₃)₂, 20 to 50 mol %;

a metaphosphate Al(PO₃)₃, 10 to 60 mol %;

fluorides BaF₂+RF₃, 20 to 90 mol %;

where R is selected from one of Y and La;

with dopant selected from one of Yb₂O₃ and YbF₃ 0.5 to 15 wt% over 100.

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[0018] A further exemplary aspect of the present invention provides an optical component, comprising:

a metaphosphate Ba(PO₃)₂, 10 to 60 mol %;

a metaphosphate Al(PO₃)₃, 10 to 60 mol %;

25 fluorides BaF₂ +RF₃, 10 to 75 mol %;

where R is selected from one of Y and La;

with dopant selected from one of Yb₂O₃ and YbF₃ 0.5 to 10 wt% over 100.

[0019] Another exemplary aspect of the present invention provides an optical
30 component, comprising:

a metaphosphate Ba(PO₃)₂, 5 to 60 mol %;

a metaphosphate $\text{Al}(\text{PO}_3)_3$, 5 to 60 mol %;
fluorides $\text{BaF}_2 + \text{RF}_3$, 10 to 90 mol %;
where R is selected from one of Y and La;
with dopant selected from one of Yb_2O_3 and YbF_3 0.2 to 20 wt% over 100.

5

[0020] Still another exemplary aspect of the present invention provides an optical component, comprising:

a metaphosphate $\text{Ba}(\text{PO}_3)_2$ in mol%,
a metaphosphate $\text{Al}(\text{PO}_3)_3$ in mol%,

10

fluorides $\text{BaF}_2 + \text{RF}_x$ in mol%,

with dopant selected from one of Yb_2O_3 and YbF_3 over 100 percent (wt%) of the composition above Yb;

where:

R is selected from the group consisting of Mg, Ca, Bi, Y, La;

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x is an index representing an amount of fluorine (F) in the compound RF_x ;

with the optical components maintaining transparency in high energy environments:

including application of high-intensity gamma-ray radiation dosage of 1.29×10^9 rads and more; and

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application of neutron energy at neutron fluxes ranging from 3×10^9 to 1×10^{14} n/cm^2 sec and more, and fluencies ranging from 2×10^{16} to 8.3×10^{20} n/cm^2 and greater; and

with a bulk laser damage threshold of $105 \pm 20 \text{ J/cm}^2$, and a surface laser damage threshold of $72 \pm 15 \text{ J/cm}^2$.

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[0021] One exemplary optional aspect of the present invention provides an optical component, wherein:

the optical component is one of a solid state laser host and solid state amplifier host, with dopant selected from one of Yb_2O_3 and YbF_3 0.5 to 5 wt% over 100.

30

[0022] Another exemplary optional aspect of the present invention provides an optical component, wherein:

the optical component is a thin disc laser host, with dopant selected from one of Yb_2O_3 and YbF_3 1 to 20 wt% over 100.

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[0023] A further exemplary optional aspect of the present invention provides an optical component, wherein:

the optical component is one of a fiber laser host and fiber amplifier host with dopant selected from one of Yb_2O_3 and YbF_3 0.5 to 3 wt% over 100.

10

[0024] Still a further exemplary optional aspect of the present invention provides an optical component, wherein:

the optical component is one of a window, mirror, and thin film covering for a solar panel, with dopant selected from one of Yb_2O_3 and YbF_3 1 to 10 wt% over 100.

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[0025] Another exemplary optional aspect of the present invention provides an optical component, wherein:

the optical components is one of a lens, with dopant selected from one of Yb_2O_3 and YbF_3 0.5 to 5.5 wt% over 100.

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[0026] A further exemplary optional aspect of the present invention provides an optical component, wherein:

a Stokes shift of the optical component is about 9%, and a fractional thermal loading of about 11%.

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[0027] Still a further exemplary optional aspect of the present invention provides an optical component, wherein:

the Yb dopant simultaneously functions to act as a desolarizer in high energy environments to maintain the optical components transparent and functions to act as laser dopant, when stimulated.

30

[0028] Another exemplary aspect of the present invention provides an optical component, comprising:

5 fluorophosphate glass system that maintains transparency in high energy environments, including in high-intensity gamma-ray radiation dosage of 1.29×10^9 rads and greater, and neutron energy at neutron fluxes ranging from 3×10^9 to 1×10^{14} n/cm² sec and greater, and fluencies ranging from 2×10^{16} to 8.3×10^{20} n/cm² and greater; and

having a bulk laser damage threshold of 105 ± 20 J/cm², and a surface laser damage threshold of 72 ± 15 J/cm².

10

[0029] Another exemplary optional aspect of the present invention provides an optical component, wherein:

the optical component is one of:

15 a solid state laser host; a solid state amplifier host; a thin disc laser host; a fiber laser host; a fiber amplifier host; a window, a thin film covering for a solar panel, a mirror and a lens.

[0030] Still another exemplary optional aspect of the present invention provides an optical component, wherein:

20 a Stokes shift of the optical component is about 9%, and a fractional thermal loading of about 11% when stimulated with 945 nm wave energy.

[0031] A further exemplary optional aspect of the present invention provides an optical component, wherein:

25 the optical components are polished to a Roughness_{p-v} of 118Å⁰ to 132Å⁰.

[0032] Still a further exemplary optional aspect of the present invention provides an optical component, wherein:

30 a draw temperature T_D of the optical components to form an optical fiber is substantially different from that of a crystallization temperature T_C , with the draw temperature equaling to about 690 °C.

[0033] Another exemplary optional aspect of the present invention provides an optical component, wherein:

5 fluorophosphate glass system includes a Yb dopant that simultaneously functions to act as a desolarizer in high energy environments to maintain the optical components transparent and functions to act as laser dopant, when stimulated.

[0034] Still another exemplary optional aspect of the present invention provides an optical component, wherein:

10 the optical component is a lens with an Abbe number of approximately 64 to 68 remains constant regardless of an increase in linear refractive index, with non-linear refractive index remaining low at about $n_2=1.42 \times 10^{-13}$ esu.

[0035] Another exemplary optional aspect of the present invention provides an optical component, wherein:

15 fluorophosphate glass system is comprised of:
a metaphosphate $\text{Ba}(\text{PO}_3)_2$ in mol%,
a metaphosphate $\text{Al}(\text{PO}_3)_3$ in mol%,
fluorides $\text{BaF}_2 + \text{RFx}$ in mol%,
20 with dopant selected from one of Yb_2O_3 and YbF_3 over 100 percent (wt%) of the composition above Yb;
where:
R is selected from the group consisting of Mg, Ca, Bi, Y, La; and
x is an index representing an amount of fluorine (F) in the compound RFx .

25 [0036] Such stated advantages of the invention are only examples and should not be construed as limiting the present invention. These and other features, aspects, and advantages of the invention will be apparent to those skilled in the art from the following detailed description of preferred non-limiting exemplary embodiments,
30 taken together with the drawings and the claims that follow.

[0037] BRIEF DESCRIPTION OF THE DRAWINGS

[0038] It is to be understood that the drawings are to be used for the purposes of exemplary illustration only and not as a definition of the limits of the invention.

Throughout the disclosure, the word “exemplary” is used exclusively to mean
5 “serving as an example, instance, or illustration.” Any embodiment described as “exemplary” is not necessarily to be construed as preferred or advantageous over other embodiments.

[0039] Referring to the drawings in which like reference character(s) present
10 corresponding part(s) throughout:

[0040] FIG. 1A is an exemplary view of a first optical component sample of the present invention in an exemplary form of an exemplary fiber core in accordance with the present invention;

15 [0041] FIG. 1B is an exemplary view of the first optical component shown in FIG. 1A, but after application of high energy in accordance with the present invention;

[0042] FIG. 1C is an exemplary view of a second optical component sample of the present invention in an exemplary form of a rectangular-cube, after the application of
20 high energy in accordance with the present invention;

[0043] FIG. 2 is an exemplary optical component of the present invention, which was subjected to a laser damage threshold test in accordance with the present invention;

25 [0044] FIG. 3A is view of an exemplary optical component of the present invention in the exemplary form of a solid state laser/amplifier host in accordance with the present invention;

30 [0045] FIG. 3B is a view of an exemplary optical component of the present invention in the exemplary form of a disc in accordance with the present invention;

[0046] FIG. 3C is a view of an exemplary optical component of the present invention in the exemplary form of a disc that may be cut, shaped, and polished into a lens in accordance with the present invention;

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[0047] FIG. 4A exemplarily shows a topography of one polished side of a cubed optical component of the present invention;

[0048] FIG. 4B is a table, which details the numerical data with respect to the surface quality in terms of polished optical component end product for the side shown in FIG. 4A;

[0049] FIG. 4C exemplarily shows a topography of another polished side of the same cubed optical component of the present invention shown in FIG. 4A; and

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[0050] FIG. 4D is a table, which details the numerical data with respect to the surface quality in terms of polished optical component end product for the side shown in FIG. 4C; and

[0051] FIG. 5 is a view of an exemplary optical component in the exemplary form of glass-rod in accordance with the present invention.

[0052] DETAILED DESCRIPTION OF THE INVENTION

[0053] The detailed description set forth below in connection with the appended drawings is intended as a description of presently preferred embodiments of the invention and is not intended to represent the only forms in which the present invention may be constructed and or utilized.

[0054] For the sake of convenience and clarity, this disclosure uses the phrase “energy” in terms of both wave and particle energies. Further, this disclosure defines high energy wave (i.e., high Electromagnetic Radiation or EMR) as those in the

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gamma ray frequencies (greater than 10^{19} Hz or higher). In addition, this disclosure defines high particle energy in terms of average neutron fluxes of at least 3×10^9 n/cm²sec, and average neutron fluences of at least 2×10^{16} n/cm². Accordingly, this invention defines the collective phrases “high energy,” “high radiation,” “high
5 radiation energy,” “high energy environment” and so on as energy defined by the above high wave energy and high particle energy parameters.

[0055] In addition, throughout the disclosure, the words “solarize” and its derivatives such as “solarization,” “solarized,” and so on define the darkening, browning, and/or
10 burning up of materials due to exposure to various amounts of radiation. The words “desolarize” and its derivatives such as “desolarization,” “desolarized,” and so on define the ability of a material to continuously resist (or reverse) the solarization process while exposed to high energy.

[0056] The optical components of the present invention may be used as a host of a system, with “host” defined as a medium (passive or active) within the system that serves to perform one or more function. One non-limiting example of an optical component of the present invention used as a host may include a laser glass (active), which is the medium that serves as laser material (or laser host material) that
20 functions to emit laser energy when excited.

[0057] The optical components of the present invention have applications in numerous fields, and may be used in high energy environments that may also require high laser damage threshold and further, may also be used to produce radiation
25 resistant shielding material. Non-limited, non-exhaustive list of examples of applications of the optical components of the present invention may include optical windows, substrate for optical mirrors, solar panel covers, space solar panel covers, lenses, fiber, and etc. Other non-limited, non-exhaustive list of examples of applications of the optical components of the present invention used as hosts may
30 include fiber amplifier host, solid state amplifier host, fiber lasers host, solid state laser hosts (e.g., thin disc laser (active mirror)), etc.

[0058] In particular, this invention provides an optical component based on fluorophosphate glass systems with Ytterbium dopant, but without using Alkali or Alkali-fluorides, lead or lead-fluoride, or bismuth metaphosphate. The optical components of the present invention are 100% lead free, which makes them environmentally friendly. In addition, the lead free optical components of the present invention further provide a very high leaching resistance, confining any potential radiation residue within the optical component. That is, after exposure to radiation energy, the optical component of the present invention maintain and confines most radiation residue within (prevents leaching), even if placed into other solutions such as water or exposed to other moisture content (e.g., acidic or base). Non-limiting examples of fluorophosphate based glass systems (but without lead or lead-fluoride), which may be used in the optical components of the present invention are disclosed in the U.S. Patent Application Publication 2003/0040421 to Margaryan, the entire disclosure of which is expressly incorporated by reference in its entirety herein.

[0059] In particular, the optical components of the present invention may include the following fluorophosphate glass systems $\{\text{Ba}(\text{PO}_3)_2, \text{Al}(\text{PO}_3)_3, \text{BaF}_2 + \text{RFx}\} + \{\text{dopant}\}$, where RFx is selected from the group $\text{MgF}_2, \text{CaF}_2, \text{BiF}_3$, or related fluorides (but not Alkali-fluorides or lead-fluoride), and the dopant may include, at minimum, Yb_2O_3 or YbF_3 . Optionally, co-dopants such as MnO or MnF_2 may also be included. The glass system $\text{Ba}(\text{PO}_3)_2\text{-Al}(\text{PO}_3)_3\text{-BaF}_2 + \text{RFx} + \text{dopant}$ use dopant from the group of oxides or fluorides of the rare earth elements over 100 percent (wt%) of the composition above Yb and mixtures thereof.

[0060] An exemplary, preferred material for the present invention are optical components that are based on or contain $\text{Ba}(\text{PO}_3)_2$, 10 to 60 mol %; $\text{Al}(\text{PO}_3)_3$, 10 to 60 mol %; $\text{BaF}_2 + \text{RFx}$, 20 to 90 mol % (where RFx is selected from the group $\text{MgF}_2, \text{CaF}_2, \text{BiF}_3$); and one of a dopant of Yb_2O_3 of 0.5 to 20 weight % or fluoride YbF_3 of 0.5 to 20 weight %. The raw compounds used for glass formation are: Barium Metaphosphate, $\text{Ba}(\text{PO}_3)_2$, and Aluminum Metaphosphate, $\text{Al}(\text{PO}_3)_3$, which are

considered chemically stable (durable) substances, resistant against dissolving in water or other moisture content (e.g., acidic or base).

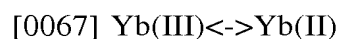
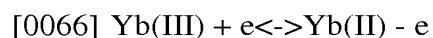
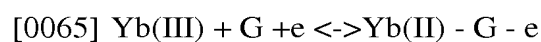
[0061] Another non-limiting example of fluorophosphate based glass system that may be used in the optical components of the present invention may include fluorophosphate glass systems with Ytterbium dopant containing $\text{Ba}(\text{PO}_3)_2$, $\text{Al}(\text{PO}_3)_3$, BaF_2 and RFx , where RFx is selected from the group MgF_2 , CaF_2 , BiF_3 , YF_3 , LaF_3 , or related fluorides (but not Alkali-fluorides or lead-fluoride) and, one of Yb_2O_3 and YbF_3 . That is, glass system $\text{Al}(\text{PO}_3)_3$ - $\text{Ba}(\text{PO}_3)_2$ - BaF_2 + RFx + dopant use dopant from the group of oxides or fluorides of the rare earth elements over 100 percent (wt%) of the composition above Yb and mixtures thereof. The introduction of Yttrium Fluoride YF_3 and Lanthanum Fluoride LaF_3 improved the overall performance and efficiency of these glasses. The preferred material for the optical components using the YF_3 may contain $\text{Ba}(\text{PO}_3)_2$, 10 to 60 mol %; $\text{Al}(\text{PO}_3)_3$, 10 to 60 mol %; BaF_2 + RFx , 20 to 90 mol %; and one of a dopant of Yb_2O_3 of 0.5 to 20 weight % or fluoride YbF_3 of 0.5 to 20 weight %.

[0062] The YF_3 dramatically increased the glass forming domain allowing the introduction of up to 60 mol% of YF_3 , and improved the optical properties such as higher Emission Cross Section from 0.87 to 1.37 pm^2 at lasing wavelength of approximately 996 nm, extremely high Gain Coefficient $G = 0.95$ to $1.65 \text{ ms} \cdot \text{pm}^4$ and Quantum Efficiency of about 90- 94 %. These improvements further enhanced the performance of the overall radiation resistant by improving the optical characteristics of the radiation resistant optical components such as radiation resistant laser host material and fibers. The LaF_3 Lanthanum Fluoride dramatically improves the Abbe Number (dispersion) to 64- 68 and reduces the chromatic aberration by about 20 - 30%. Stable Abbe Number and low chromatic aberration is extremely important for the radiation resistant lenses. The above improved characteristics due to the introduction of LaF_3 further enhances the accuracy and the precision of the radiation resistance lenses and allows the creation of smaller and flatter lenses. The reduction of the sizes of the lenses increases their overall application in different industries,

including optical based electronics systems. The presence of $\text{BaF}_2 + \text{RF}_x$ (YF_3 , LaF_3 , CaF_2 , MgF_2 , and BiF_3) effectively increases the chemical durability of the laser material. In the grouping of glasses according to chemical stability of non-silicate glasses relating to humidity or moisture, the optical components of the present invention are considered to be stable.

[0063] It should be noted that although references to optical components and in particular, glass systems used in the optical components throughout most (but not all) of the remainder of the disclosure may be directed to non-limiting examples of fluorophosphate based glass systems disclosed in the U.S. Patent Application Publication 2003/0040421 to Margaryan, these references are only meant as illustrative and for convenience of example and should not be limiting.

[0064] Radiation resistant characteristics of the optical components of the present invention provide high resistance against high levels of energy without change in the transparency (e.g., browning or darkening of the optical component – no solarization). The combination of unique molecular structure, such as large atomic radius, high electro-negativity of fluorine, and the reverse change of valency of Yb (III) dopant enables these optical components to achieve high solarization resistance. During the gamma ray or neutron fluxes (and fluencies) exposure, the Yb (III) dopant creates a continuing de-solarization process that enable the optical component of the present invention to remain transparent due to the Yb (III) having a remarkably high transformation of valency of approximately 90-95%. That is, when the Yb (III) is bombarded by the gamma, neutron or other high energy (radiation/particle), the transformation of the valency of Yb from Yb(III) to Yb(II) and vice versa constantly reoccurs, and allows the glass matrix to remain transparent, in accordance with the following:



[0068] where G is energy of the Gamma ray, and e is the electron.

[0069] In order for Yb (III) to become ionized and to create the transformation process of Yb (III) to Yb (II) and vice versa, a 6.4 eV (electron volt) energy is required. Wavelengths starting from 190 nm (e.g., far Ultraviolet - UV) up to high levels of X-Ray and Gamma ray are capable of producing the required 6.4 eV or higher for the Yb (III) dopant to achieve the reverse or continuing transformation, thereby, maintain the optical components of the present invention transparent in high energy environments. The Electron Volt Energy for each Wavelengths can be measured by utilizing the following formula:

$$E = hf = \frac{hc}{\lambda} = \frac{1240 \text{ nm}}{\lambda} \text{ eV}$$

Where E is energy, f is frequency, λ is the wavelength of a photon, h is Planck's Constant and c is the speed of light.

[0070] Two different optical component samples of the present invention have been tested in high-energy environments (i.e., high levels of gamma radiation and neutron energy), with the result that the samples maintained their transparency. FIG. 1A is an exemplary view of the first optical component sample of the present invention in the exemplary form of a fiber core only (without the cladding) with exemplary dimensions of about 179 μm of diameter, before the application of any high energy radiation. Further included with the fiber core of the present invention illustrated in FIG. 1A is an optional organic acrylate-coating (of about 284 μm diameter), which enables users to actually handle the fiber core shown in FIG. 1A. FIG. 1B is an exemplary view of the same first optical component sample shown in FIG. 1A, but after application of high energy. FIG. 1C is an exemplary view of a second optical component sample of the present invention in the exemplary form of a rectangular-

cube with exemplary dimensions of 3mm x 5mm x 5mm, after the application of high energy.

[0071] It should be noted that both of the optical component samples of the present invention (FIG. 1A and FIG. 1C) were transparent in the visible spectral region before exposure to any radiation. The tests that were conducted for both samples of the present invention were in a high-intensity gamma-ray environment, and were done so at a level of 1.8×10^6 rad per hour for 30 days in Cobalt-60 irradiator, where the total gamma-radiation dosage was 1.29×10^9 rad. After withstanding such high levels of radiation, both of the optical component samples of the present invention remained transparent with no occurrence of any solarization. As shown in FIG. 1B, the actual optical sample fiber remained clear and transparent (sections 102). The darkened sections 104 of the fiber sample of the present invention shown in FIG. 1B is the optional organic acrylate-coating that burned as a result of the exposure to high energy environment, which is easily wiped clean with a cloth. Further, as illustrated in FIG. 1C, the second optical component sample of the present invention also remained transparent.

[0072] In addition, a second set of identical optical components (same as above optical component samples, including same size and dimensions as above) of the present invention underwent high energy neutron testing. Both optical components were transparent in the visible spectral region before exposure to any radiation. The tests for neutron radiation were conducted at neutron fluxes ranging from 3×10^9 to 1×10^{14} n/cm² sec and fluencies ranging from 2×10^{16} to 8.3×10^{20} n/cm² for both samples. When exposed to the above radiation for over 90 days, both of the optical component samples of the present invention maintained their transparency, with identical results as those illustrated in FIG. 1B and 1C. Accordingly, the radiation resistant characteristics of the optical components of the present invention provide high resistance against high levels of energy (wave or particle) without change in the transparency (e.g., no browning or darkening of the optical component – no solarization).

[0073] In addition to providing high radiation resistance (wave or particle), the optical components of the present invention also have a high level of resistance against laser damage. FIG. 2 exemplarily shows an optical component of the present invention, which was subjected to a laser damage threshold test (detailed below). As detailed in table II below, the optical components of the present invention have a high laser damage threshold, which is in part due to the addition of Ytterbium as a dopant. Accordingly, the optical components of the present invention (for example, a solid state laser or amplifier host) may be used in high energy environments as high energy optical components with high levels of laser damage threshold. In addition, due to unique spectroscopic properties, the optical components of the present invention can be used for ultraviolet, visual and near infrared optics in the band of about 350 to approximately 5,000 nm. The optical components of the present invention have high chemical durability, and are free of alkali-fluorides and bismuth metaphosphate.

[0074] Current commercially available high power vitreous optical components are mainly based on Nd or Er dopants. On the other hand, the optical components of the present invention use Yb dopants, which produce more than 1 Kw of energy and have low heat dissipation when stimulated to generate a laser effect. For example, fractional thermal loading of about 11% is produced when the optical laser product of the present invention having Yb dopant is stimulated or pumped with 945 nm wave energy. Conventional optical components that are doped with Nd generate a large amount of thermal loading of about 32% when stimulated or pumped with only 808 nm wave energy. It should be noted that generated thermal load in high power lasers is a great concern in that the higher the generated thermal loading, the lower the laser energy output. As the thermal load increases, it reduces the laser output efficiency. In the above example, the output efficient of the high power optical component of the present invention with Yb dopant is at approximately 89%. Conventional optical components with Nd dopant have a mere 68% output efficiency with the remaining energy converted and dissipated as heat. In addition, Quantum Defects or Stokes shift are only 9% in Yb doped laser optical components of the present invention, where as

they are about 24% in Nd doped laser optical components. That is, the actual wavelength output from the laser host of the present invention with Yb dopant is varied by only 9% from its supposed ideal wavelength output. This is significant in that, at high powers, the laser host of the present invention (with the Yb dopants) generate laser wavelengths that are close to being pure (or at worst, shift by a mere 9%) from their supposed ideal laser wavelength output.

[0075] During the excitation process (for laser applications) under high levels of energy, the Yb dopant in the optical components of the present invention can concurrently perform two functions. One function of the Yb is to act as a desolarizer by maintaining the optical component of the present invention transparent due to the constant desolarization process of Yb when used in high energy environments (mentioned above). The other function of the Yb within the optical component of the present invention is to act as laser dopant, when stimulated. That is, when used as a laser optical component, some of the Yb dopants within the optical component of the present invention are excited to generate output laser energy, when stimulated. It should be noted that both functions can occur simultaneously. That is, the optical component of the present invention when used as a laser product and placed in a high energy environment, when excited, the Yb dopant will function as a laser dopant and also, function as desolarizer. Accordingly, the optical components of the present invention are ideal for use in laser applications, high energy applications, or simultaneously, in both laser and high energy applications. For example, the use of optical components of the present invention as laser hosts are ideal for use in high energy laser devices that may be used for the generation of nuclear energy through the process of nuclear fusion or in applications that need to work in deep space (where exposure to different types of radiation is imminent).

[0076] Examples of effective compositions and properties of the optical components of the present invention are illustrated in Table I based on mol percent and weight percent.

[0077] Table I

Composition of Glass (mol%)			Yb ₂ O ₃ or YbF ₃ Dopant (wt%)	Refractive Index	Density	Emission Cross-section pm ²	Gain Coefficient (ms*pm ⁴)	Quantum Efficiency
Ba(PO ₃) ₂	Al(PO ₃) ₃	BaF ₂ + RF _x	Over 100%	nD	g/cm ³	@ 996nm	G	%
40	48	12	1	1.5878	4.15	0.87	0.95	90
35	13	52	1	1.5886	4.20	0.95	1.55	92
28	10	62	1	1.5895	4.28	1.29	1.60	93
10	16	74	1	1.5914	4.32	1.37	1.65	94
Where RF _x is one of MgF ₂ , CaF ₂ , BiF ₃ , YF ₃ , LaF ₃ .								

[0078] In the above example, Yb₂O₃ or YbF₃ would be used as dopant.

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[0079] The following procedures were used in testing for laser damage threshold (both bulk and surface) of the optical components of the present invention shown in FIG. 2:

10 [0080] 1 - Started at a low fluence/irradiance and tested 10 sites at 1 shot/site. Based on the number of sites damaged, the percentage of damage at that fluence was calculated.

15 [0081] 2 – Next, the fluence/irradiance was increased and another 10 sites at single shot/site were performed.

[0082] 3 – This procedure was repeated until a fluence/irradiance damaged 10/10 sites.

20 [0083] 4 – Next, the plotted percentage damage was tested versus the Fluence/Irradiance. The data was fitted to a line and the intercepted with the x-axis of the threshold value. All values are detailed in the following table II.

[0084] The bulk laser damage threshold for the optical components of the present invention was found to be 105 ± 20 J/cm². The laser damage threshold tests showed that surface laser damage threshold for the optical components of the present invention was found to be 72 ± 15 J/cm². The laser source was: Nd:YAG, Beam Radius = 9.5 micron (Hwe -1 M), Pulsewidth = 1.7 ns (Hwe - 1 M), Wavelength = 1.064 micron. This newly discovered laser damage threshold data relating to the optical components of the present invention seems to be the highest among most known commercially available optical components currently in existence.

[0085] Table II

Beam Radius = 9.5 μm (HW1/eM)

Pulsewidth = 1.7 ns (HW1/eM)

Wavelength = 1.064 μm

Testing method: 10 sites at each fluence, 1
shot per site

% DMG = percentage ($N/10 * 100$) of sites damaged at given
fluence

	<u>Avg Fluence(J/cm²)</u>	<u>Avg Irradiance (GW/cm²)</u>	<u>%DMG</u>
<u>Bulk</u>	100	33.1876	0
	125	41.4845	10
	145.1153	48.16031485	20
	182.8112	60.67069616	50
	225.0739	74.69668157	60
	248.028	82.31458645	70
	270.4212	89.7463645	40
	295.6787	98.12871882	70
	319.9747	106.1919986	30
	371.7115	123.3621978	80
	424.5899	140.911298	80
	481.3942	159.763286	100
<u>Surface</u>	9.714412	3.22398243	0
	21.25153	7.052877027	0
	47.91108	15.9005484	0
	72.02686	23.90400168	0
	99.76801	33.11063192	30
	115.3912	38.29559336	30
	131.6353	43.68662377	60
	148.6606	49.33690225	50
	166.8075	55.35943438	40
	186.5968	61.9270522	50

[0086] As stated above, the optical components of the present invention have applications in numerous fields that may be used in high energy environments that may also require high laser damage threshold. Non-limited, non-exhaustive examples of applications may include windows, substrate for optical mirrors, space solar panel covers, lenses, fiber, fiber amplifier hosts, fiber laser hosts, solid state amplifier hosts, solid state laser hosts (e.g., thin disc laser (active mirror)), etc. The amount or concentration of Yb_2O_3 or YbF_3 dopants within the optical components of the present invention to provide radiation resistant products with superior optical characteristics may vary depending on the specific application of the optical component, including the optical component physical dimensions. For example, for active optical components of the present invention (e.g., laser hosts, etc.) there is a need to balance dopant-concentration quenching in relation to optimized optical emission and optical component radiation resistance characteristics of the optical component when Yb_2O_3 or YbF_3 dopants are added. On the other hand, for non-active optical components of the present invention (e.g., an optical window), there is a need to balance dopant-concentration quenching in relation to optimized transparency and optical component radiation resistance characteristics when Yb_2O_3 or YbF_3 dopants are added. Accordingly, the Table III below is an exemplary, non-exhaustive, non-limiting, listing of the amounts or concentration of Yb_2O_3 or YbF_3 dopants needed for a set of exemplary products.

[0087] Table III

Composition of the Optical Component	Yb ₂ O ₃ (YbF ₃)(wt.%) Dopet Radiation Resistant with High Laser Damage Threshold Optical Components				
	Solid State Laser / Amplifier host	Thin Disc Laser host	Fiber Laser / Amplifier host	Windows, Mirrors, Solar Panel Covers	Lens
Ba(PO ₃) ₂ , 10 to 60 mol %; Al(PO ₃) ₃ , 10 to 60 mol %; BaF ₂ +RFx, 20 to 90 mol %;	0.5 - 5	1 - 10	0.5 - 3	1 - 6	1 - 5
Ba(PO ₃) ₂ , 20 to 50 mol %; Al(PO ₃) ₃ , 10 to 60 mol %; BaF ₂ +RFx, 20 to 90 mol %;	1 - 3	2 - 15	0.5 - 2.5	2 - 8	0.5 - 4.5
Ba(PO ₃) ₂ , 10 to 60 mol %; Al(PO ₃) ₃ , 10 to 60 mol %; BaF ₂ +RFx, 10 to 75 mol %;	0.5 - 2.5	3.5 - 6	1 - 1.5	1.5 - 10	1.5 - 5.5
Ba(PO ₃) ₂ , 5 to 60 mol %; Al(PO ₃) ₃ , 5 to 60 mol %; BaF ₂ +RFx, 10 to 90 mol %;	0.2 - 3	4 - 20	0.5 - 2	3 - 10	2 - 5
Where RFx is one of MgF ₂ , CaF ₂ , BiF ₃ , YF ₃ , LaF ₃ .					

- 5 [0088] FIG. 3A is a view of an exemplary solid state laser/amplifier host in accordance with the present invention, which may comprise of composition and dopant amounts or concentrations detailed in Table III. For example, as detailed in Table III, for a solid state laser/amplifier host shown in FIG. 3A, the optical component composition may include Ba(PO₃)₂, 10 to 60 mol %; Al(PO₃)₃, 10 to 60 mol %; BaF₂+RFx, 20 to 90 mol %; with Yb₂O₃ or YbF₃ dopant concentration between 0.5 to 5 wt%. As detailed in Table III, RFx is one of MgF₂, CaF₂, BiF₃, YF₃, LaF₃. Accordingly, the solid state laser/amplifier host of the present invention shown in FIG. 3A with the mentioned composition concentrations detailed in Table III provides low dopant-concentration quenching, high optical emission, and high radiation resistance.

[0089] FIGS. 1C and 2 are views of exemplary windows in accordance with the present invention, which may be shaped and polished into mirrors, thin film solar panel covers, etc. The optical components of FIGS. 1C and 2 may comprise of

composition and dopant amounts or concentrations detailed in Table III. For example, as detailed in Table III, for a window shown in FIGS. 1C and 2, the optical component composition may include $\text{Ba}(\text{PO}_3)_2$, 10 to 60 mol %; $\text{Al}(\text{PO}_3)_3$, 10 to 60 mol %; BaF_2+RFx , 20 to 90 mol %, with Yb_2O_3 or YbF_3 dopant concentration of about 5 wt%. As detailed in Table III, RFx is one of MgF_2 , CaF_2 , BiF_3 , YF_3 , LaF_3 . Accordingly, the window of the present invention shown in FIGS. 1C and 2 with the mentioned composition concentrations detailed in Table III provides low dopant-concentration quenching, high optical transparency, and high radiation resistance.

[0090] As mentioned above, the windows shown in FIGS. 1C and 2 can be made into a mirror by a coating on one side and used as a mirror substrate. In addition, the glass windows of FIGS. 1C and 2 can be cut and polished and be used as a solar panel cover, with a thickness of approximately 200 to 250 microns. That is, the optical components of the present invention (shown in FIGS. 1C and 2) may also be prepared in large plates, the sizes of which are based on the manufacturing facility. In general, the glass plate may be softened in temperatures ranging from about 550 °C to 650 °C and rolled through rolling machinery. Once the glass is reduced to about a 3 mm thickness, the plates are transferred into a final shaping and polishing facility to achieve the desired final shape and thickness. In the experiment to demonstrate the practical manufacturing of the optical solar panel cover of the present invention, the optical components shown were successfully polished up to 250 microns in thickness, which considerably improved transparency by about 90% from 250 nm to 5000 nm. The thinner the glass is, the higher its transparency.

[0091] FIG. 3B is a view of an exemplary optical component of the present invention in the form of a thin disc in accordance with the present invention, which may comprise of composition and dopant amounts or concentrations detailed in Table III. For example, as detailed in Table III, for a thin disc laser hosts shown in FIG. 3A, the optical component compositions may include $\text{Ba}(\text{PO}_3)_2$, 10 to 60 mol %; $\text{Al}(\text{PO}_3)_3$, 10 to 60 mol %; BaF_2+RFx , 20 to 90 mol %; with Yb_2O_3 or YbF_3 dopant concentration of approximately 1 - 10 wt%. As detailed in Table III, RFx is one of MgF_2 , CaF_2 ,

BiF₃, YF₃, LaF₃. Accordingly, the thin disc laser hosts of the present invention shown in FIG. 3B with the mentioned composition concentrations detailed in Table III provides low dopant-concentration quenching, high optical emission, and high radiation resistance. It should be noted that the thin disk laser host material can be sliced, shaped, and polished to approximate thickness of 150 to 200 microns with varying diameters, depending on application.

[0092] FIG. 3C is a view of an exemplary optical component of the present invention in the exemplary form of a disc that may be cut, shaped and polished into a lens in accordance with the present invention, which may comprise of composition and dopant amounts or concentrations detailed in Table III. For example, as detailed in Table III, for a lens, the optical component compositions may include Ba(PO₃)₂, 10 to 60 mol %; Al(PO₃)₃, 10 to 60 mol %; BaF₂+RF_x, 20 to 90 mol %; with optimum Yb₂O₃ or YbF₃ dopant concentration is approximately 1 - 5 wt%. As detailed in Table III, RF_x is one of MgF₂, CaF₂, BiF₃, YF₃, LaF₃. Accordingly, the lens of the present invention with the mentioned composition concentrations detailed in Table III provides low dopant-concentration quenching, high optical transparency, and high radiation resistance.

[0093] The optical component of the present invention in the form of a lens has an Abbe Number that is remarkably constant. That is, the change of linear refractive index in Ytterbium doped optical components of the present invention used as lens has been found to increase with increasing dopant concentration due to the dense packing of dopant materials into host materials, while the Abbe Number for the optical lens of the present invention is found to be remarkably constant, i.e., approximately 64-68 for a wide dopant concentration. On the other hand, the non-linear refractive index remained low at $n_2=1.42 \times 10^{-13}$ esu (electrostatic unit). The following table IV provides the optical characteristics of the lens of the present invention.

[0094] Table IV

Yb ₂ O ₃	0 wt %	1 wt %	2 wt %	3 wt %	4 wt %	5 wt %
nF 486 nm	1.5933	1.5940	1.5950	1.5965	1.5984	1.6003
nD 589 nm	1.5872	1.5878	1.5888	1.5898	1.5919	1.5940
nC 656 nm	1.5847	1.5850	1.5860	1.5873	1.5894	1.5915
Abbe Number	68.28	65.31	65.42	64.10	65.76	67.50

[0095] The manufacturing process of the optical components of the present invention can be maximized by using the non-limiting, exemplary pot melt process, where materials are manufactured in an inert atmosphere created by Ar or other inert gases. The melting of the main batch (comprised of Al(PO₃)₃- Ba(PO₃)₂-BaF₂+ RF_x + dopant) is conducted in different types of crucibles, depending on the final optical component application and use. In general, the presence of Platinum (Pt) is considered to be a major contamination issue for processing of most optical components. The presence of Pt in optical components substantially lowers their radiation resistance levels. Accordingly, for high radiation energy applications the preferred, non-limiting example of a crucible used may include the use of vitreous carbon or graphite crucibles, rather than a Platinum based crucible. In general, the use of vitreous carbon or graphite crucibles control the overall allowable contamination of the main batch with respect to Pt, up to 500 ppb of Platinum (Pt). On the other hand, for application not requiring high levels of radiation resistance 95% Pt and 5% Au non-stick crucible, or, alternatively, 100% Pt crucible may be used. In these applications, the Pt contamination was found to be 5000 ppb, which is acceptable for optical components, including for those with some levels of radiation resistance.

[0096] To continue with the pot melt process, the main batch is melted at approximately 1100°C to 1280 °C (e.g., preferably, 1260°C) for 4 to 6 hours or more until a homogeneous melt is achieved. The homogeneity of the melt is enhanced by mixing the melt. Next, the glass of the present invention is poured into a mold for

cooling and annealing. The cutting, shaping, and polishing of the optical components is then produced from the main bulk for desired applications.

[0097] The next process is to cut the optical components into desired configurations for required applications, which would require the polishing of the cut surfaces of the optical components. The optical components of the present invention can be polished in accordance with industry requirements. However, it should be noted that most conventional fluorophosphate based glass systems cannot be polished to levels in accordance with the present invention (indicated in the tables of FIGS. 4B and 4D) because they have a very low chemical durability in that they dissolve in polishing substances, such as water during the polishing process.

[0098] FIG. 4A exemplarily shows one polished side of a cubed optical component of the present invention, and FIG. 4B is a table, which details the numerical data with respect to the surface quality in terms of polished optical component end product for the side shown in FIG. 4A. FIG. 4C exemplarily shows another polished side of the same cubed optical component of the present invention shown in FIG. 4A, and FIG. 4D is a table, which details the numerical data with respect to the surface quality in terms of polished optical component end product for the side shown in FIG. 4C. It should be noted that the physico-chemical and thermo-mechanical characteristics of the optical components of the present invention enable the polishing of the present invention optical components at levels indicated in the FIGS. 4B to 4D. The following table V is an exemplary, non-exhaustive, non-limiting listing of physico-chemical and thermo-mechanical characteristics of the optical components of the present invention:

[0099]

[00100] TABLE V:

Present Invention Optical Components	Yb ₂ O ₃ dopant
Thermo-mechanical	
Knoop Hardness (kgf/mm ²)	335.6 to 359.2
Thermal Expansion (micrometer / °C)	0.02295 to 0.02309
Physical	
Density (g/cc)	4.248 to 4.574

[00101] It should be noted that the act of polishing of the optical components of the present invention to levels detailed in FIGS. 4A to 4D in accordance with the present invention is required and important for most optical applications, which is not possible with most conventional fluorophosphate glass systems. FIG. 4A is an actual microscopic photograph of a small section (about 20 micrometers) of a side of the polished surface of the sample optical component of the present invention. FIG. 4C is also an actual microscopic photograph of a small section (about 8 micrometers) of another side of the polished surface of the same sample optical component of the present invention shown in FIG. 4A. The indicated horizontal lines A, B, C, and D are horizontal scanning lines of the polished surface of the sampled optical component. The sampled optical component was scanned along the horizontal lines A, B, C, and D for measuring surface variations (e.g., depth) after sample was completely polished, with the resulting data illustrated in the corresponding respective tables of FIGS. 4B and 4D.

[00102] FIGS. 4B and 4D are tables that show extrapolated data from the measured scan lines A, B, C, and D of the respective FIGS. 4A and 4C. As illustrated in the tables of FIGS. 4B and 4D, each respective row of the table corresponds to respective scan lines A, B, C, and D in respective FIGS. 4A and 4C. As illustrated in table of FIG. 4B, the extrapolated data from the respective scan lines of FIG. 4A has an average Roughness Peak-to-Valley (Roughness_{P-V}) of about 118A⁰, with an average Root-Mean-Square (RMS) of about 21.0 A⁰, and an average of about 16.4A⁰. As illustrated in table of FIG. 4D, the extrapolated data from the respective scan lines of FIG. 4C has an average Roughness Peak-to-Valley (Roughness_{P-V}) of about 132A⁰, with an average Root-Mean-Square (RMS) of about 24.2A⁰, and an average of about 19.1A⁰.

[00103] The results of (FIG. 4A and FIG. 4C) of the same optical component of the present invention clearly indicate that the surface of the polished sampled optical component of the present invention is near perfect. That is, the polished surface has

minimal roughness. This negligible roughness meets and exceeds the polished surface requirements for most (if not all) optical applications. In addition, it should be noted that the minimal, negligible roughness level measurement of the polished surface of the sampled optical component enables the use of the optical components of the present invention in very high power lasers by improving their overall performance. That is, the reduced roughness substantially reduces surface losses due to laser light scattering, which are minimized as a result of polishing. In addition, such high levels of polishing enables the final product to be tested at various laser damage threshold levels (detailed above). As mentioned, most conventional optical components cannot be polished to levels in accordance with the present invention (indicated in the tables of FIGS. 4B and 4D) because they have a very low chemical durability in that they dissolve in polishing substances, such as water during the polishing process.

[00104] As stated above, the optical components of the present invention have applications in numerous fields that may be used in high energy environments that may also require high laser damage threshold, one non-limited example of which is an optical fiber (active or passive). Generally, the conventional fluorophosphate based glasses have a tendency to become crystallized during what is known as the fiber drawing process to produce optical fibers. Accordingly, conventional fluorophosphate based glasses are generally not used to produce optical fiber components. The drawback with most conventional fluorophosphate based glasses is that the rate of change of their viscosity in relation to variations in temperature is usually high, wherein crystallization takes place. That is, small increments in increases in temperature greatly reduces their viscosity, within which crystallization occurs, which prevents the use of most conventional fluorophosphate based glasses for making optical fiber products. In other words, with most conventional fluorophosphate based glasses, their drawing (or pulling temperature) T_D (when they become sufficiently viscous to be pulled into a fiber) is very close (i.e., similar) to their crystallization temperature T_C , so they crystallize. Other factors contributing to crystallization may include, for example, the use of alkali elements in the glass

composition, which has the tendency to increase crystallization during the fiber draw process. However, the optical components of the present invention do not have alkali elements, and have pulling or drawing temperature T_D that is substantially different from their crystallization temperature T_C . Accordingly, the optical components of the present invention are easily modified to manufacture and produce optical fibers with high radiation resistance and high laser damage thresholds, and were successfully pulled to a transparent fiber (FIGS. 1A and 1B), using the following relatively low cost techniques.

[00105] The manufacturing process for producing fiber (the “fiber draw”) (exemplarily shown in FIGS. 1A and 1B) from the optical components of the present invention ($\text{Al(PO}_3)_3$ - $\text{Ba(PO}_3)_2$ - BaF_2 + RF_x + dopant) was generally done within an inert gas atmosphere, such as Ar gas. The fiber drawing (or the fiber production from the “rod” of glass system produced from the Melt Pot process above) is conducted in an inert gas (e.g., Ar) atmosphere by the application of heat as follows. An example of an optical component in the exemplary form of a glass-rod in accordance with the present invention is shown in FIG. 5.

[00106] The heat up schedule for the optical component of the present invention in the form of a rod shown in FIG. 5 was as follows:

- 3°C/minute up to just above the glass transition temperature (T_g) of 540 °C, 5 minute hold there, then 5°C/min. to 620 °C, the anticipated draw temperature.
- 10 minute hold at 620 °C. When no drop obtained, increased to 630 °C.
- 5 minute hold at 630 °C. When no drop obtained, increased to 640 °C.
- 5 minute hold at 640 °C. When no drop obtained, increased to 650 °C.
- 5 minute hold at 650 °C. When no drop obtained, increased to 660 °C.
- 5 minute hold at 660 °C. When no drop obtained, increased to 670 °C.
- 5 minute hold at 670 °C. When no drop obtained, increased to 690 °C.
- 5 minute hold at 690 °C. When no drop obtained, increased to 710 °C.
- Obtained a drop at 710 °C. Lower temperature to 690 °C.

[00107] As noted above, the “rod” glass of the present invention (shown in FIG. 5) was heated at 3°C/minute up to just above the glass transition temperature (T_g) of 540 °C. The glass transition temperature (T_g) is the threshold wherein the glass transitions from a solid state to a more malleable (e.g., soft) condition. The rod glass of the present invention was then held at 540 °C for about 5 minute, which created a uniform thermal condition for the whole rod. Thereafter, the “rod” glass was then exposed to a progressively increasing rate of temperature of about 5°C/min. up to 620 °C, which is the anticipated draw temperature for the optical fiber component of the present invention.

[00108] As further noted above, the rod glass was held at 620 °C for about 10 minutes. However, no “drop” or “fall” in the rod glass was observed. That is, the rod glass did not become sufficiently malleable or soft where it could stretch and drop or fall onto a fiber draw reel (shown in FIG. 1A) for drawing or pulling the rod glass into strands of the optical fiber component of the present invention. Accordingly, the “rod” glass was then exposed to an increased temperature of 630 °C, where the rod glass was held at 630 °C for about 5 minutes. However, no “drop” or “fall” in the rod glass was observed, and accordingly, the temperature was increased to about 640 °C. The process continued on as noted above until a drop was obtained at 710 °C, where the temperature was then lowered to 690 °C.

[00109] The following are the draw observations from the above fiber draw method. The initial drop obtained at 710 °C showed that the draw tension was too low, accordingly, the temperature was lowered to 690 °C. The fluorophosphate rod of the present invention appeared to draw well at this temperature, with some slight surface crystallization noted on the initial drop, but was clear up as the draw was established. Over 1,200 feet of the optical fiber component sample of the present invention was collected (drawn or pulled) during this experiment from the fluorophosphates glass system of the present invention in the form of an exemplary rod shown in FIG. 5 with dimensions of about 10 mm (diameter) and about 97.1 mm (length). After the draw, the fiber strength noted in tension appeared good for this

type glass, and the rod was cooled down at 3°C/min. It should be noted that similar process may be used for producing the core and the cladding elements of the optical fiber component of the present invention.

5 [00110] Although the invention has been described in considerable detail in language specific to structural features and or method acts, it is to be understood that the invention defined in the appended claims is not necessarily limited to the specific features or acts described. Rather, the specific features and acts are disclosed as preferred forms of implementing the claimed invention. Stated otherwise, it is to be
10 understood that the phraseology and terminology employed herein, as well as the abstract, are for the purpose of description and should not be regarded as limiting. Therefore, while exemplary illustrative embodiments of the invention have been described, numerous variations and alternative embodiments will occur to those skilled in the art. For example, the optical components of the present invention may
15 be used in numerous other applications that have not been explicitly mentioned. In addition, it should be noted that none of the FIGS are to scale. Such variations and alternate embodiments are contemplated, and can be made without departing from the spirit and scope of the invention.

20 [00111] It should further be noted that throughout the entire disclosure, the labels such as left, right, front, back, top, bottom, forward, reverse, clockwise, counter clockwise, up, down, or other similar terms such as upper, lower, aft, fore, vertical, horizontal, oblique, proximal, distal, parallel, perpendicular, transverse, longitudinal, etc. have been used for convenience purposes only and are not intended to imply any
25 particular fixed direction or orientation. Instead, they are used to reflect relative locations and/or directions/orientations between various portions of an object.

[00112] In addition, reference to “first,” “second,” “third,” and etc. members throughout the disclosure (and in particular, claims) is not used to show a serial or
30 numerical limitation but instead is used to distinguish or identify the various members of the group.

[00113] In addition, any element in a claim that does not explicitly state "means for" performing a specified function, or "step for" performing a specific function, is not to be interpreted as a "means" or "step" clause as specified in 35 U.S.C. Section 5 112, Paragraph 6. In particular, the use of "step of," "act of," "operation of," or "operational act of" in the claims herein is not intended to invoke the provisions of 35 U.S.C. 112, Paragraph 6.

CLAIMS

What is claimed is:

1. An optical component, comprising:
a metaphosphate $\text{Ba}(\text{PO}_3)_2$, 10 to 60 mol %;
5 a metaphosphate $\text{Al}(\text{PO}_3)_3$, 10 to 60 mol %;
fluorides $\text{BaF}_2 + \text{RF}_3$, 20 to 90 mol %;
where R is selected from one of Y and La;
with dopant selected from one of Yb_2O_3 and YbF_3 0.5 to 10 wt% over 100.
- 10 2. An optical component, comprising:
a metaphosphate $\text{Ba}(\text{PO}_3)_2$, 20 to 50 mol %;
a metaphosphate $\text{Al}(\text{PO}_3)_3$, 10 to 60 mol %;
fluorides $\text{BaF}_2 + \text{RF}_3$, 20 to 90 mol %;
where R is selected from one of Y and La;
15 with dopant selected from one of Yb_2O_3 and YbF_3 0.5 to 15 wt% over 100.
3. An optical component, comprising:
a metaphosphate $\text{Ba}(\text{PO}_3)_2$, 10 to 60 mol %;
a metaphosphate $\text{Al}(\text{PO}_3)_3$, 10 to 60 mol %;
20 fluorides $\text{BaF}_2 + \text{RF}_3$, 10 to 75 mol %;
where R is selected from one of Y and La;
with dopant selected from one of Yb_2O_3 and YbF_3 0.5 to 10 wt% over 100.
4. An optical component, comprising:
25 a metaphosphate $\text{Ba}(\text{PO}_3)_2$, 5 to 60 mol %;
a metaphosphate $\text{Al}(\text{PO}_3)_3$, 5 to 60 mol %;
fluorides $\text{BaF}_2 + \text{RF}_3$, 10 to 90 mol %;
where R is selected from one of Y and La;
with dopant selected from one of Yb_2O_3 and YbF_3 0.2 to 20 wt% over 100.
- 30 5. Optical components, comprising:

a metaphosphate $\text{Ba}(\text{PO}_3)_2$ in mol%,

a metaphosphate $\text{Al}(\text{PO}_3)_3$ in mol%,

fluorides $\text{BaF}_2 + \text{RF}_x$ in mol%,

with dopant selected from one of Yb_2O_3 and YbF_3 over 100 percent (wt%) of the

5 composition above Yb;

where:

R is selected from the group consisting of Mg, Ca, Bi, Y, La;

x is an index representing an amount of fluorine (F) in the compound RF_x ;

with the optical components maintaining transparency in high energy

10 environments:

including application of high-intensity gamma-ray radiation dosage of 1.29×10^9 rads and more; and

application of neutron energy at neutron fluxes ranging from 3×10^9 to 1×10^{14} n/cm² sec and more, and fluencies ranging from 2×10^{16} to 8.3×10^{20} n/cm² and greater;

15 and

with a bulk laser damage threshold of 105 ± 20 J/cm², and a surface laser damage threshold of about 72 J/cm².

6. The optical component as set forth in Claim 5, wherein:

20 the optical component is one of a solid state laser host and solid state amplifier host, with dopant selected from one of Yb_2O_3 and YbF_3 0.5 to 5 wt% over 100.

7. The optical component as set forth in Claim 5, wherein:

25 the optical component is a thin disc laser host, with dopant selected from one of Yb_2O_3 and YbF_3 1 to 20 wt% over 100.

8. The optical component as set forth in Claim 5, wherein:

30 the optical component is one of a fiber laser host and fiber amplifier host with dopant selected from one of Yb_2O_3 and YbF_3 0.5 to 3 wt% over 100.

9. The optical component as set forth in Claim 5, wherein:

the optical component is one of a window, mirror, and thin film covering for a solar panel, with dopant selected from one of Yb_2O_3 and YbF_3 1 to 10 wt% over 100.

10. The optical component as set forth in Claim 5, wherein:

5 the optical components is one of a lens, with dopant selected from one of Yb_2O_3 and YbF_3 0.5 to 5.5 wt% over 100.

11. The optical component as set forth in Claim 5, wherein:

10 a Stokes shift of the optical component is about 9%, and a fractional thermal loading of about 11%.

12. The optical component as set forth in Claim 5, wherein:

15 the Yb dopant simultaneously functions to act as a desolarizer in high energy environments to maintain the optical components transparent and functions to act as laser dopant, when stimulated.

13. An optical component, comprising:

20 fluorophosphate glass system that maintains transparency in high energy environments, including in high-intensity gamma-ray radiation dosage of 1.29×10^9 rads and greater, and neutron energy at neutron fluxes ranging from 3×10^9 to 1×10^{14} n/cm² sec and greater, and fluencies ranging from 2×10^{16} to 8.3×10^{20} n/cm² and greater; and

25 having a bulk laser damage threshold of about 105 J/cm², and a surface laser damage threshold of about 72 J/cm².

14. The optical component as set forth in Claim 13, wherein:

the optical component is one of:

30 a solid state laser host; a solid state amplifier host; a thin disc laser host; a fiber laser host; a fiber amplifier host; a window, a thin film covering for a solar panel, a mirror and a lens.

15. The optical component as set forth in Claim 14, wherein:

a Stokes shift of the optical component is about 9%, and a fractional thermal loading of about 11% when stimulated with 945 nm wave energy.

5 16. The optical component as set forth in Claim 13, wherein:

the optical components are polished to a Roughness_{p-v} of 118Å⁰ to 132Å⁰.

17. The optical component as set forth in Claim 14, wherein:

10 a draw temperature T_D of the optical components to form an optical fiber is substantially different from that of a crystallization temperature T_C, with the draw temperature equaling to about 690 °C.

18. The optical component as set forth in Claim 13, wherein:

15 fluorophosphate glass system includes a Yb dopant that simultaneously functions to act as a desolarizer in high energy environments to maintain the optical components transparent and functions to act as laser dopant, when stimulated.

19. The optical component as set forth in Claim 14, wherein:

20 the optical component is a lens with an Abbe number of approximately 64 to 68 remains constant regardless of an increase in linear refractive index, with non-linear refractive index remaining low at about $n_2=1.42 \times 10^{-13}$ esu.

20. The optical component as set forth in Claim 13, wherein:

25 fluorophosphate glass system is comprised of:
a metaphosphate Ba(PO₃)₂ in mol%,
a metaphosphate Al(PO₃)₃ in mol%,
fluorides BaF₂ + RFx in mol%,
with dopant selected from one of Yb₂O₃ and YbF₃ over 100 percent (wt%) of the composition above Yb;
30 where:
R is selected from the group consisting of Mg, Ca, Bi, Y, La; and

x is an index representing an amount of fluorine (F) in the compound RF_x .

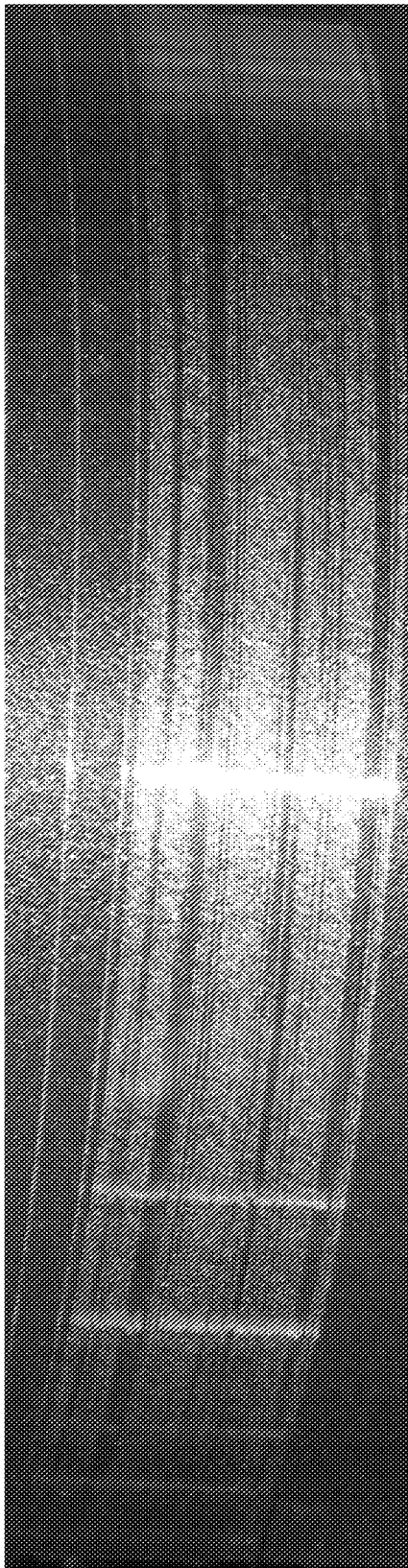


FIG. 1A

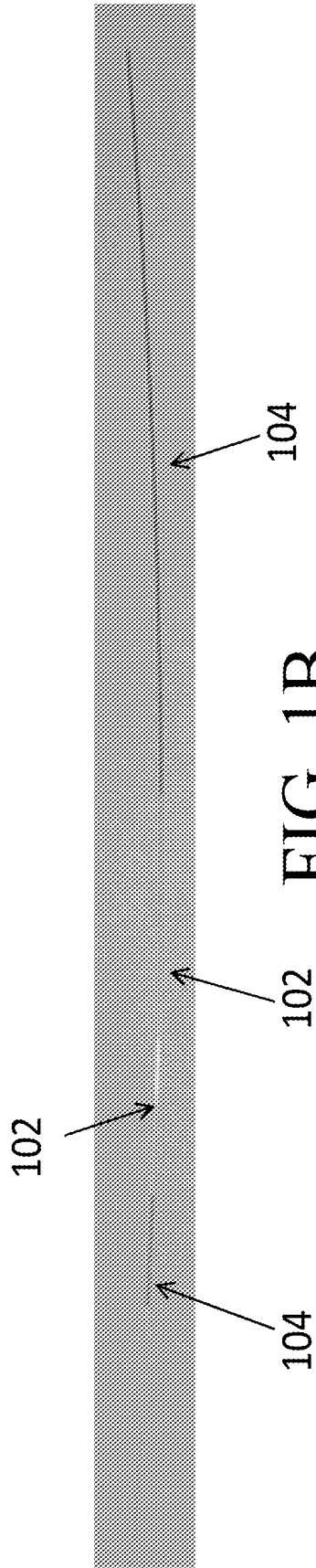


FIG. 1B

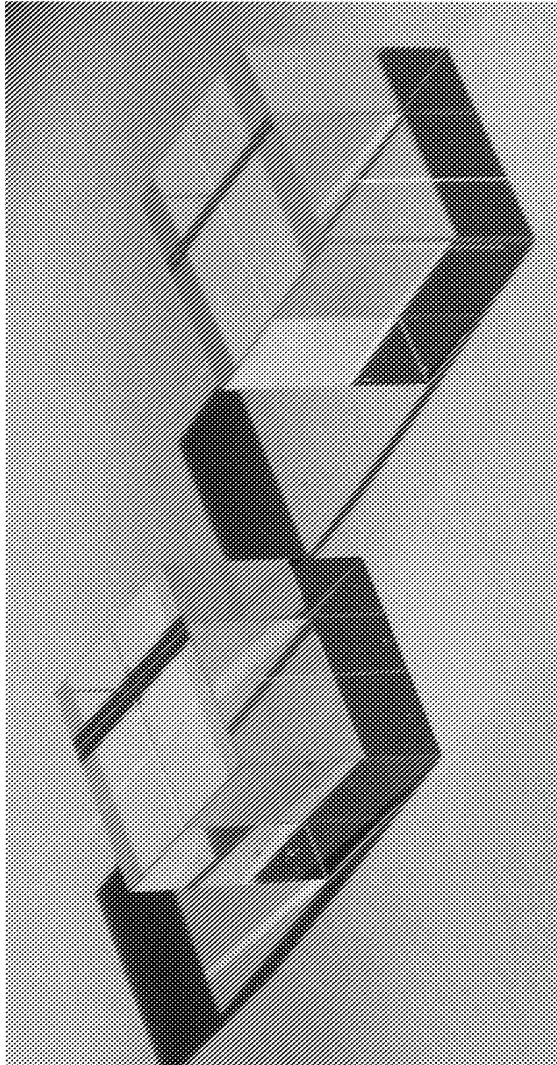


FIG. 2

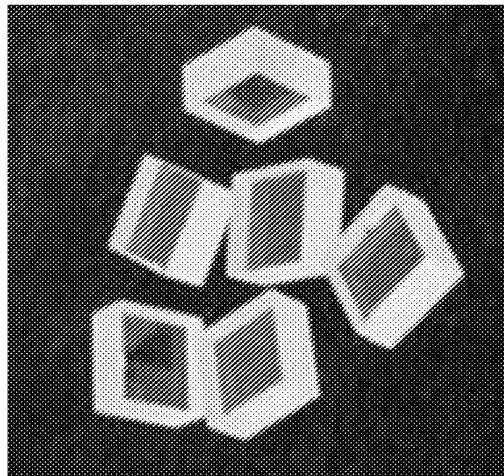


FIG. 1C

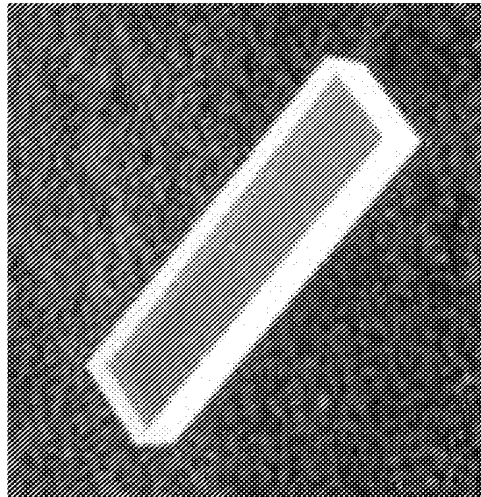


FIG. 3A

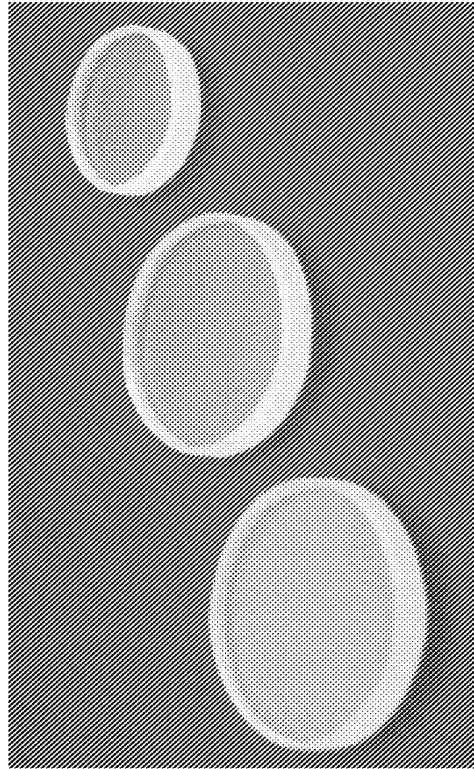


FIG. 3B

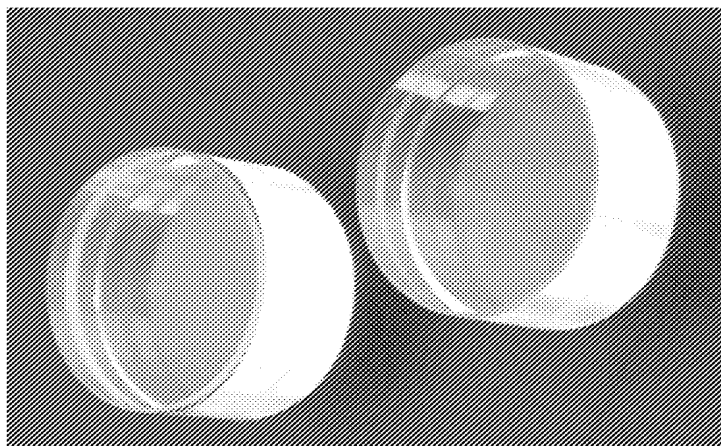


FIG. 3C

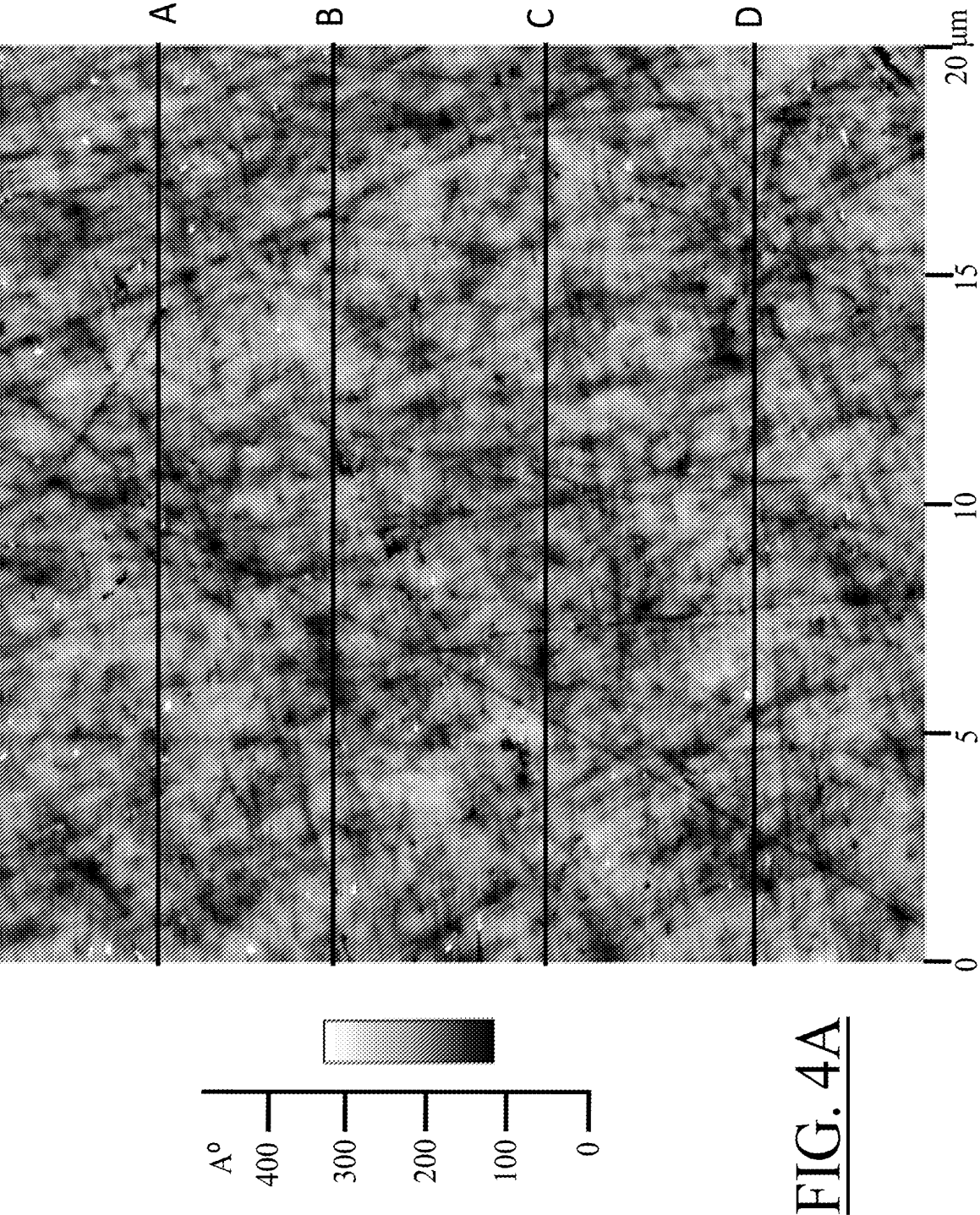


FIG. 4A

Scan Line	Roughness $P-V$	RMS	Ave
A	103 \AA^0	18.7 \AA^0	14.6 \AA^0
B	109 \AA^0	21.9 \AA^0	17.4 \AA^0
C	104 \AA^0	19.3 \AA^0	14.9 \AA^0
D	157 \AA^0	23.8 \AA^0	18.9 \AA^0
Ave.	118 \AA^0	21.0 \AA^0	16.4 \AA^0

FIG. 4B

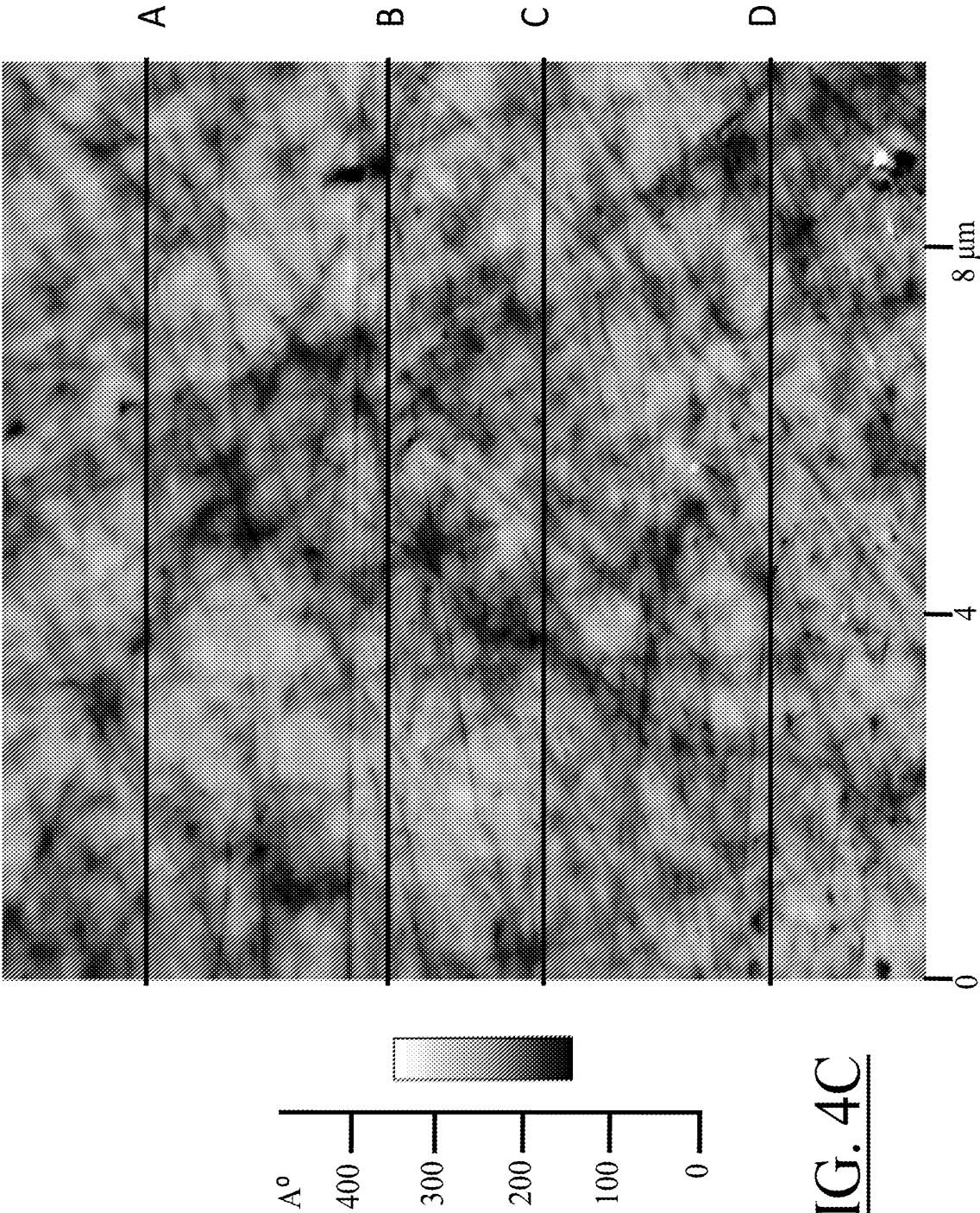


FIG. 4C

Scan Line	Roughness _{P-V}	RMS	Ave
A	102 A°	22.3A°	17.8A°
B	243A°	30.6A°	22.2A°
C	102A°	24.6A°	20.4A°
D	83.5A°	19.4A°	16.0A°
Ave.	132A°	24.2A°	19.1A°

FIG. 4D

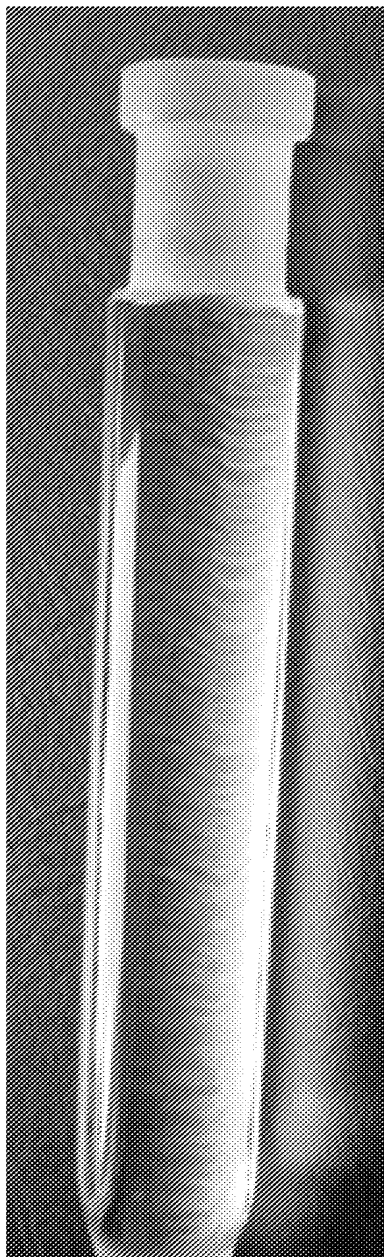


FIG. 5

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 09/62652

A. CLASSIFICATION OF SUBJECT MATTER IPC(8) - C03B 11/00, 23/00; C03C 3/247 (2010.01) USPC - 501/30, 44; 65/64 According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) USPC - 501/30, 44; 65/64 Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched USPC - 501/30,44,32,45;65/32,5,64,66,424,27,29,117 (text search - see search terms below) Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) PubWEST (PGPB,USPT,OC,EPAB,JPAB); DialogPro (General Research); Google Patents optic, component, glass, metaphosphate, Ba(PO ₃) ₂ , %, Al(PO ₃) ₂ , fluoride, BaF ₂ , RF3, Y, La, lanthide,lanthanide, YB, dope, transperance, neutron, flux, n/cm2, gamma, rads, laser,damage, threshold, J/cm2, fluorophosphate, stokes shift, thermal load, host, fiber		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2007/0010390 A1 (MARGARYAN et al.) 11 January 2007 (11.01.2007), entire document especially abstract, para [0002], [0005], [0018]-[0021], [0026], [0029]-[0036], Tables I and II and claim 1.	1-20
Y	US 2005/0188724 A1 (IKENISHI et al.) 01 September 2005 (01.09.2005), entire document, especially abstract, para [0003], [0024], [0042], [0113], [0163], [0268], [0274]-[0276] and Tables 14-16.	1-4
Y	US 4,142,088 A (HIRSCH) 27 February 1979 (27.02.1979), entire document especially col 1, ln 45-59, col 3, ln 29-44, col 4, ln 58-66, col 8, ln 10-15.	5-20
Y	US 4,182,664 A (MAKLAD et al.) 08 January 1980 (08.01.1980), entire document especially abstract, col 2, ln54 - col 3, ln 22, col 4, ln 3-10 and claim 12.	5-20
Y	US 5,846,638 A (MEISSNER) 08 December 1998 (08.12.1998), entire document especially abstract, col 1, ln 18-35, col 5,ln 66 - col 6, ln 21, col 9, ln 41-56, col 10, ln 24-45, col 13, ln 50-67, col 14, ln 16-49, col 17, ln 8-44.	7, 10, 16
Y	US 2006/0245460 A1 (LUO et al.) 02 November 2006 (02.11.2006), entire document especially para [0003], [0038], [0045]-[0052], [0058], [0060].	11, 15
Y	US 2006/0033983 A1 (DAI et al.) 16 February 2006 (16.02.2006), entire document especially abstract, para [0011], [0080]-[0083].	17
<input checked="" type="checkbox"/> Further documents are listed in the continuation of Box C. <input type="checkbox"/>		
* Special categories of cited documents: "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
Date of the actual completion of the international search 15 February 2010 (15.02.2010)		Date of mailing of the international search report 05 MAR 2010
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201		Authorized officer: Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 09/62652

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5,526,369 A (HAYDEN et al.) 11 June 1996 (11.06.1996), entire document especially abstract, col 1, ln 10-32, col 2, ln 28-43, col 3, ln 5-38, col 5, ln 46-59, col 6, ln 49-67, col 11, ln 31-50 and Tables 1 and 2.	19
A	US 3,941,672 A (TANAKA et al.) 02 March 1976 (02.03.1976), entire document especially Fig. 6, col 3, ln 54 - col 4, ln 17.	16
A	US 2005/0259944 A1 (ANDERSON et al.) 24 November 2005 (24.11.2005), entire document especially para [0183]-[0189], [0196].	17
A	US 4,120,814 A (IZUMITANI et al.) 17 October 1978 (17.10.1978), entire document.	19
A	US 2005/0058424 A1 (ISHIOKA et al.) 17 March 2005 (17.03.2005), entire document especially abstract, para [0001], [0002], [0021]-[0028], [0038]-[0042], [0047]-[0051], [0070], [0071], [0093 and Tables 3-5.	1-20